Harmonic Distortion Assessment of a DC Railway Traction Power System

Introduction

- Harmonics generated by multiple-pulse rectifiers are well known EMI disturbance to trackside equipment in a dc traction railway environment.
- The magnitude and frequency of harmonic currents can vary with many factors that may cause an impact on the functions of safety critical electronic equipment such as the signaling system.
- This paper describes a case study in which a model of dc traction power supply and traction current return circuit has been used for assessing the effect of dc harmonics on the signaling system in a quantitative manner.

Objective

- The objective of this exercise is to verify that the dc harmonics generated by the 1500 V dc traction power supply will not cause any troubles to the normal operation of signaling equipment. Mitigation measures will be proposed if any risk of disturbance is identified.
- Source of EMI is the transformer-rectifier unit in traction substations generating harmonics under normal and abnormal conditions.
- Victims susceptible to the EMI include audio frequency coded track circuits and radiating cable loops and beacons installed on the track.

Modelling of the System

- The System includes the 24-pulse Rectifiers in Traction Substations (TSS), Electric Multiple Unit Trains (EMU), Overhead Line System (OHL) and Rails with traction return bonding cables.
**Modelling of the System**

- $V_h$ is the harmonic voltage source representing the harmonic spectrum generated by the transformer rectifier unit in traction substations.
- $Z_{TSS}$, $Z_{OHL}$, $Z_{RAIL}$, and $Z_{EMU}$ are the equivalent impedance of the system components.
- Snapshots of changing values in a dynamic model.

**Challenges in the Model**

- Circuit parameters changing with time:
  - Number of EMUs in the same electrical section varies.
  - EMU locations are time dependent.
  - In-take load currents also change according to the motoring, coasting or braking condition of EMU.
- Simplify the network by considering one EMU at a time.
- Approximation of multiple EMU effects by using Weighting Factors.
- Worst case considerations for the snapshot of densest trains within one electrical section by referring to the Headway Chart for peak hour operations.

**Methodology**

- Fast Fourier Transform of the rectified voltage waveforms output from the TSS under different conditions of:
  - ac inputs
  - the rectifier
- Modelling and Approximations for the following relationships:
  - TSS and Trains
  - Train and Rail
- Estimation of the harmonic currents in the return rail that affect the signalling equipment:
  - Frequency
  - Level

**Additional cases:**

- Case I - One Diode Arm Broken
- Case II - 5th Harmonic in Input Voltage
- Case III - Rectifier Input Voltage Unbalance
- Case IV - Rectifier Output Phase Mismatch
- Case V - Mains Frequency Fluctuation
- Case VI - Rectifier Transformer Input Voltage Unbalance
- Case VII - Rectifier Transformer Input Voltage Unbalance
- Case VIII - 5th Harmonic in Input Voltage with Rectifier Overlap Angle
- Case IX - 5th Harmonic in Input Voltage with Rectifier Overlap Angle
- Case X - Unbalanced Input Voltage with Rectifier Overlap Angle
- Case XI - EMU Line Filter

In the assessment, harmonics in d.c. traction power supply were estimated in the following steps (base case):

- Determine harmonic voltage spectra generated by 12-pulse transformer rectifier units.
- Estimate harmonic currents flowing through an EMU and the aggregate effect of several EMU.
- Estimate harmonic currents flowing in the return rails that will interfere with the signalling equipment.
**Methodology**

**Step 1: Determine Harmonic Voltage Spectra**

Harmonic voltages based on 12-pulse transformer rectifier units were investigated taking into consideration a number of equipment failure and imperfections scenarios.

**Step 2: Estimate Harmonic Currents Flowing Through an EMU and the Aggregate Effect of Several EMU**

- **Simplified Model of TSS and Single EMU**
  - $V_{H1}$
  - $Z_{EMU1}$
  - $I_{H1}$

- **Circuit for Weighting Factor Estimation**
  - One-sided Approximation
  - Current Divider Approximation Multiplier on Single Train

**Step 3: Harmonic Current Flowing in Return Rails**

- "S" Bond between EMU and TBB
- $I_3$ and $I_4$
- $D_1$ and $D_2$

Unbalanced Current flowing through the Track Circuit as a function of train position.

- The immunity levels of various trackside signaling equipment are defined as the maximum permissible in-band harmonic currents flowing in the rails.
- Check for In-band EMI levels to determine severity of disturbance.
Methodology

**d.c. Harmonic - Train LC Filter Parameter Variation**

- **Range of C₁:** variation between $0.01 \, C₁$ to $10 \, C₁$

Summary of Findings

- Track circuits were identified as the most vulnerable type of signaling equipment under influence of harmonic currents.
- The estimated harmonic currents within the 3dB bandwidth of the signaling equipment were compared with the corresponding maximum permissible current limits.
- It is possible that the harmonic currents at two of the Track Circuit operating frequencies will likely exceed the permissible limits.
- Other harmonics generated by the traction power supply equipment in the interested frequency ranges are within limits with a quite generous safety margin.

Conclusion

- Different in-feed supply conditions, power supply equipment failure and imperfections scenarios have been assessed in this exercise.
- Generally speaking, the estimated amount of harmonics so generated will not exceed the limits as specified by the signaling contractor except in a few specific conditions.
- Based on the HDA findings, the EMC design and test specifications for rolling stock and signaling system can be developed and assessed.

Thank You